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The effect of air velocity on the performance of the direct evaporative cooling system

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Abstract. This experimental study aimed to determine the effect of airflow velocity on the performance of a direct evaporative cooling system. Rectangular-shaped honeycomb cooling pads with a length of 34 cm, a width of 25 cm, and a thickness of 3.5 cm are used as cooling media. The main parameters of the study are low air velocity (2.3 ms^{-1}), medium (3.2 ms^{-1}), and high velocity (3.7 ms^{-1}). The data collected include dry bulb temperature, wet bulb temperature, output air temperature, input and output air velocity, input and output humidity, and solar radiation. These data are used to determine saturation efficiency, cooling capacity, temperature decreases, and feasibility index. The experimental results are presented in the form of tables and graphs and analysed based on existing theories. The results showed that the evaporative cooling system could produce output temperatures up to 27.5°C with input 31.4°C at low airspeed, 27.97°C with input 31.47°C at medium speed, and 27.70°C with input 31.30°C at high airspeed. It was concluded that a low airflow rate would add to the cooling efficiency, and the higher the airflow rate, the lower the cooling efficiency. The results showed that evaporative cooling is achievable with a feasibility index of $19.89 \leq F^* \leq 20.67$. The results also affirmed that cooling capability is higher where the feasibility indexes are comparatively low.

1. Introduction

The use of air conditioning nowadays is very advanced and used in various aspects of human life. Air conditioning for comfort is done by controlling temperature, humidity and cleaning the air to produce comfortable and clean air. With proper temperature, humidity, and even hygiene conditions, air conditioning can create a comfortable environment at low energy demand [1]. Energy is an essential factor in heating, ventilation, and air conditioning (HVAC) application as it is one of the main issues needed to be addressed sustainably.

Evaporative cooling technology is one of the air conditioners using the oldest principle, in which the air is cooled by the process of water evaporation [2]. Evaporative cooling can be called adiabatic saturation. The adiabatic Saturation device is a device that disperses air through a splash/spray of water [3]. There are three types of the evaporative cooling process is direct evaporative cooling, indirect evaporative cooling, and indirect-direct evaporative cooling [4]. The temperature, humidity, and cleanliness of the air provided, on the other hand, are more conducive to comfort.

2. Direct evaporative cooling (DEC)

For the conditioning of room air, direct evaporative cooling is a standard process. The direct evaporative cooler (DEC) uses a fan to force warm air from outside through a porous pad onto which a continuous water spray is enabled to cool the air. When water evaporates from the moistened pad, the heat is absorbed by the water. Direct evaporative cooling has the disadvantage of cool only up to the inlet air's wet-bulb temperature. The sensible heat is converted to latent heat in this heat and mass exchange operation. As a result, direct evaporative cooling has two significant drawbacks, air retains moisture due to heat exchange with water, and temperature reduction is limited to the inlet air wet-bulb temperature.

Evaporation is the transformation of a liquid into water vapour when it is below its boiling point. At room temperature, water can evaporate by absorbing heat from the air. When the temperature of the environment or the water rises, the water evaporates more quickly. Evaporation takes place on the liquid's surface [5]. Numerous variables influence the evaporation mechanism, as shown in figure 1.

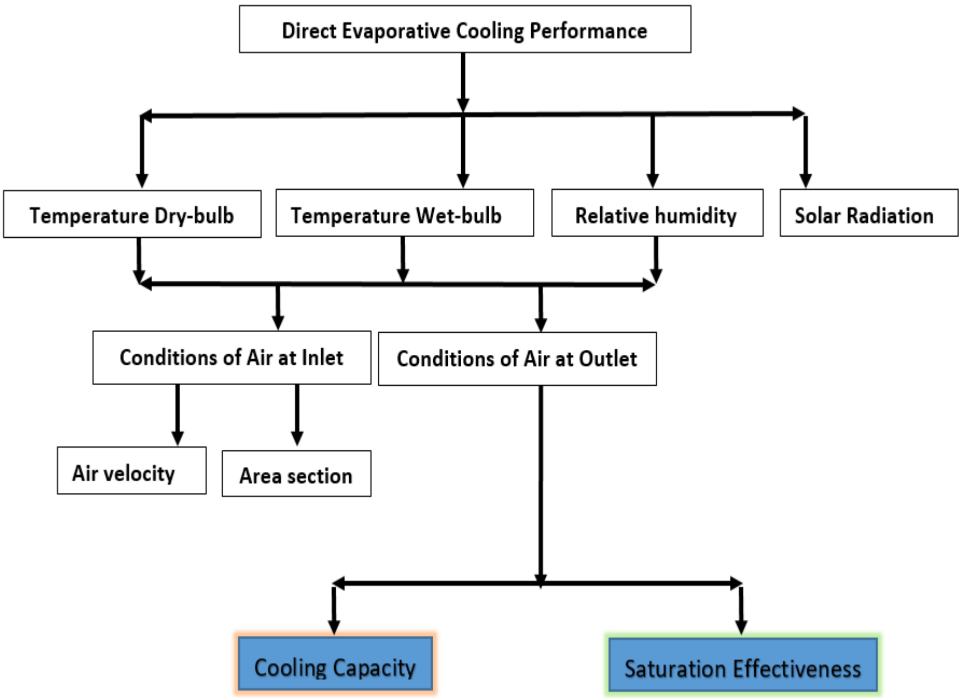


Figure 1. Main parameters of Direct Evaporative Cooling process.

The measurement of air velocity is just as critical as the other variables. The most important feature to consider when designing and operating these systems is the velocity of the air flowing through the pad (pad evaporative cooling systems). If this function is not selected correctly, the system's construction and maintenance costs will skyrocket. Evaporative cooling can increase air humidity, but it requires a continuous flow of outside air and the proper exhaust temperature [6]. Airflow not only has a cooling effect but can also cause discomfort in humans.

Air velocity refers to the rate at which air moves through space. The air is usually moved naturally, by convection or by fans. A device called an anemometer is used to measure air velocity. The anemometer is placed at the evaporative cooling unit's inlet to test the inlet air velocity. The mass flow rate is then calculated using the inlet air velocity, density, and the cross-section area of the inlet air duct [7]. There are various methods for raising air velocity, including increasing the fan's speed and size. X. She *et al*. [8] studied the airflow patterns of an evaporative cooling and dehumidification process for a hybrid refrigeration system. They discovered that they are useful for system design and optimization.

In an experiment set up following the principles of AMCA (Air Movement and Control Association) and ASHRAE, Koca *et al*. (1991) [9] evaluated the functionality of three separate cellulose pads

(American Society of Heating, Refrigerating and Air-Conditioning Engineers). The study's first pad had a thickness of 10 cm and a chamfer angle of 45 to 45 degrees, while the second pad had a thickness of 15 cm and a chamfer angle of 45 to 45 degrees, and the third pad had a thickness of 15 cm and a chamfer angle of 30 to 30 degrees. The study shows that at 1.5 to 2.5 ms^{-1} air velocity, the cooling efficiency of a pad with a 10 cm thickness and a 45°C chamfer angle yields 73% to 90%.

Cruz *et al*. (2006) [10] evaluated the efficiencies of three different pad materials at various temperatures and air velocities. The maximum cooling efficiency (80 % or more) was reached at 3.2 ms^{-1} air velocity at temperatures of 32 to 34°C in a study performed at four different temperature ranges with air velocity of 1.6, 3.2, 4.8, and 5.6 ms^{-1}, respectively.

Kocaturk and Yildiz (2006) [11] investigated some efficiency characteristics of a cellulose-based evaporative cooling pad at various air velocities. The air velocity through the cooling pad was set to 0.5, 1.0, and 2.0 ms^{-1}. The study reported that the cooling efficiency was 77% to 84 %, the temperature decreases between 6.7 and 5.6°C, and the amount of vaporized water was measured between 0.078 and 0.210 L min^{-1} m^{-2}.

Making an evaporative cooler that works in a hot, humid climate like Malaysia while maintaining human thermal comfort is a difficult task nowadays. Studies have shown that several factors are affecting the performance of evaporative coolers. One crucial factor would be air velocity variation to humidity. The most significant element that must be carefully determined throughout the design and operation of these devices is the velocity of the air moving through the pad. If this feature is not picked correctly, the system's construction and operation expenses will skyrocket. However, the remaining installation and operation costs have a negative impact on the firms' competitiveness.

Thus, this experimental study aimed to determine the effect of airflow velocity on the performance of a direct evaporative cooling system and help the people who design and operate these systems. The scope of study is to investigated the effect of air velocity in three air situations. In low air velocity (2.3 ms^{-1}), medium (3.2 ms^{-1}), and high velocity (3.7 ms^{-1}).

2.1 Methods and Experiment Setup

The study was carried out in Kolej Komuniti Kota Marudu, Sabah, at a location of 6.0367°N, 116.1186°E and the measurement was taken between 10:00 am and 01:00 pm in April 2021. The direct evaporative cooling (DEC) used for this study consisted of a 65-watt axial blower and a 10watt submersible water pump to circulate water in the system up to 1400 L/hour. The water is sprinkled on the upper side of the pad while air passes through the unit horizontally. A honeycomb cooling pad was used as cooling media with a length of 34 cm, a width of 25 cm and a thickness of 3.5 cm. Experiments were carried out to evaluate the performance of the direct evaporative cooling unit with different airflow rates.

Thermocouple's Type-K with an accuracy of ± 0.1°C was used to measure the air temperature. The relative humidity was measured using a humidity meter located at the inlet and outlet points of the evaporative cooling unit. At the same time, dry wet-bulb temperatures for ambient air were recorded using the sling psychrometer. An anemometer was installed at the inlet point of the evaporative cooling unit to measure the air velocity. The mass flow rate of air entering the evaporative cooling unit was determined by using the air velocity and the cross-section area of the inlet duct. A Solar Power Meter was used to record the solar radiation in the test location. To show that the weather condition is clear sky. The axial fan of the evaporative air cooler operates with three modes of speed: low, medium, and high. The water tank's water to the cooling pad is pumped by a submersible water pump located outside the water tank with a connecting pipe to the cooling tube. The schematic diagram and the experimental setup is shown in figure 2.

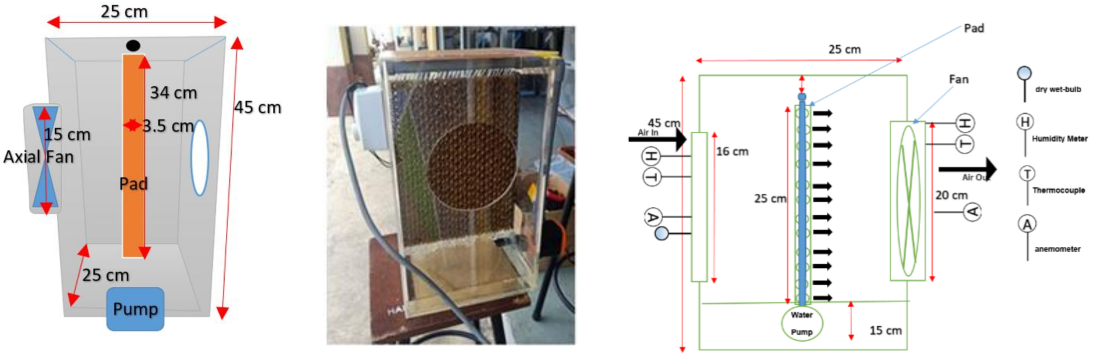


Figure 2. Diagram and photograph of a direct evaporative cooling and its pad.

Measurements were taken every 10 minutes for a total of 18 readings from all sensors throughout the 3-hour testing period. The air velocity was set using fan regulator at 2.3, 3.2, and 3.7 ms^{-1} and measurements were taken to compare the performance of DEC at different parameters. Measured inlet air velocities were used to calculate air mass flow rate in each test to achieve the same experimental conditions for results. Each reading was taken six times to ensure near-steady state conditions achieved and accurate readings. All the experiments were carried out in nearly identical conditions.

3. Performance evaluation

The evaporative cooling (EC) performances of the tested materials were evaluated based on the equations given below: The temperature drop of air (ΔT) across the EC pad is obtained with equation 1.

$$\Delta T = T_1 - T_2 \tag{1}$$

where T_1 for the inlet temperature and T_2 for outlet temperature.

The evaporative cooling saturation efficiency (ε) is calculated via equation 2 as described by ASHRAE (2001) [12]:

$$\varepsilon = (T_1 - T_2)/(T_1 - T_{wb}) \times 100 \tag{2}$$

where T_{wb} is evaporative inlet wet bulb temperature °C.

The mass flow rate of air across the EC pad should be measured to calculate the cooling capability. As shown in equation 1, it was determined by multiplying the measured air velocity at the outlet V by the average density of air, and the cross-section area (AC), of the material sample. The air mass flow rate is calculated using equation 3.

$$M_a = \rho VAC \tag{3}$$

where the sensible cooling capacity is calculated using the temperature drop and air mass flow rate as shown in equation 4.

$$Q_c = maC_p\,(T_1 - T_2) \tag{4}$$

Feasibility index (F*) is specified in equation 5

$$F^* = T_{wb} - (T_1 - T_{wb}) \tag{5}$$

where: Q_c is cooling capacity (kJ/h), ma for air flow rate (kg/s), C_p for specific heat of air (J/kgK).

A small F* number designates better feasibility for an evaporative cooling system. It denotes the ability of evaporative cooling to provide thermal comfort. The evaporative cooling effect increases as the temperature differential between the two rises. According to Watt, J. R 1963 [13], comfort cooling is when the F* is less than 10. When the F* is between 11 and 16, relative (lenitive) cooling is achieved, though F* > 16 is not recommended to use evaporative cooling systems [14]. The average daytime F* in Malaysia is 18, higher than the recommended margins.

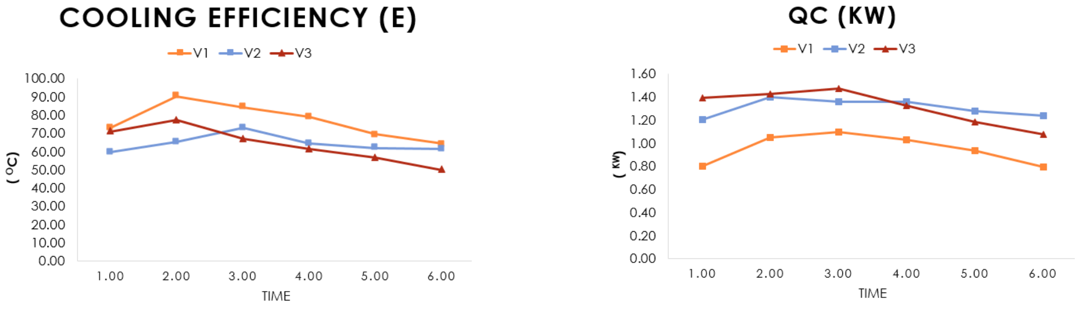
4. Result and discussion

Experimental data were collected and analysed. The data presented in the form of temperature drop achieved, cooling efficiency, cooling capacity and feasibility index. As shown in table 1, the highest average temperature drop was measured at 2.3 ms^{-1}, at 4.21^{O}C. While at a higher air velocity of 3.2 m/s and 3.7 m/s, the temperature decrease was almost identical to 3.5^{O}C and 3.6^{O}C, respectively. The highest temperature drop implies better average cooling efficiency at 76.66%, an approximate 10% better than the other velocity configuration. However, experimental data show higher air velocity institutes higher cooling capacity Q_c with the highest air velocity recorded 1.31 kW cooling capacity. This is expected as higher velocity means higher mass flow rates and more heat absorbed during the evaporation process. This result shows an exciting discovery where contact factors and air retention are essential in the cooling pad. A slower airflow through the cooling pad allows better surface contact on the pad surface and thus better heat transfer than higher velocity airflow. R.K. Kulkarni and S.P.S. Rajput (2010) [15] reported similar findings where the higher the air mass flow rate through the cooling surface, the less time the air stream is in contact with the wetted pad. As a result, less water is evaporated at the pad leads to lower relative humidity and temperature reduction in the space conditioned by the cooler. Similar studies show almost a similar trend, Timmos and Baughman (1984) [16], for example, calculated an average evaporative cooling saturation efficiency of 80% at 0.9 ms^{-1} air velocity in a poultry house with evaporative pad cooling in the South-east area of the United States. Other researchers achieve almost similar efficiency [17 – 20] at a range of 50% to 90%, which shows the achieved efficiency in the current DEC is acceptable. The average feasibility index was also analysed and showed impractical numbers, with the best Feasibility Index calculated at 19.89, higher than the preferred minimum index number, 18. One possible cause for this result is the high humidity recorded during the experiments; the relative humidity was relatively high at 70.8% - 72.5%, which is typical for a tropical climate.

Table 1. Performance of Direct Evaporative Cooling at a various air velocity.

Technical parameters	**Performance (Average)** **Low (2.3 m/s)**	**Medium (3.2 m/s)**	**High (3.7 m/s)**
Dry-Bulb Inlet T_1 (^{O}C)	31.72	31.47	31.30
Web-bulb Inlet T_{WB} (^{O}C)	26.20	26.00	25.60
Dry-Bulb Outlet T_2 (^{O}C)	27.5	27.97	27.70
Temperature Decreases (^{O}C)	4.21	3.50	3.60
Cooling Efficiency (%)	76.66	64.24	63.82
Feasibility Index (F)	20.67	20.53	19.89
Cooling Capacity Q_C (KW)	0.95	1.30	1.31
Relative humidity RH_{in} (%)	70.8	72.32	72.50
Relative humidity RH_{out} (%)	73.05	74.98	75.85

The evaporative cooling saturation efficiency and capacity variations were also observed for an averaged single day, as shown in figures 3(a) and 3(b). The evaporative cooling saturation efficiency and capacity vary because of changes in relative humidity at the site of the experiment. Both data show the efficiency and cooling capacity were higher at the start of the experiments and increased until it reaches a maximum value before it gradually decreases towards the experiment's end, a left eschewed dome shape. This behaviour is co-related to the environment humidity of the experiment site, where the humidity is slightly lower at the beginning and becomes higher throughout the experiments.



(a) (b)

Figure 3. Evaporative cooling saturation efficiency and Cooling Capacity Trends from 10 am to 1 pm.

5. Conclusion

In general, the evaporative cooling saturation efficiency of the direct evaporative cooler is influenced by air velocity, water flow rate, relative humidity, solar radiation, and the type of pad used. In this study, the air velocity variation was used to study the performance of the direct evaporative cooler and its feasibility in a Malaysian climate. It is found that air velocity does play an important role in increasing the cooling capacity of a direct evaporative system where the highest cooling capacity was measured at 1.31 kW at the highest air velocity. However, air velocity has an inverse effect on efficiency of the DEC where highest efficiency was measured at lowest velocity configuration at 76.66%. Slow air velocity promotes better retention time of air on the cooling pad surface and allows more evaporation process took place and reduces temperature. In the future, more study needs to be done to design better cooling pad that allows better efficiency at higher velocity.

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References

[1] Misaran M S, Sing C F and Adzrie M 2019 Study of wyee-tee duck design at various protrusion and guide vane location using CFD *CFD Letters* **11**(11) 39-47
[2] Jain J K and Hindoliya D A 2011 Experimental performance of new evaporative cooling pad materials *Sustainable Cities and Society* **1**(4) 252-6
[3] Stoecker W F and Jones J W 1982 *Refrigeration and Air Conditioning* New York: The McGaw-Hill
[4] Wang S K and Wang S K 2000 *Handbook of air conditioning and refrigeration* New York: McGraw-Hill
[5] Liberty J T, Ugwuishiwu B O, Pukuma S A and Odo C E 2013 Principles and application of evaporative cooling systems for fruits and vegetables preservation. *Int. J. Current Eng. and Tech.* **3**(3) 1000-6
[6] Bhatia A Principles of Evaporative Cooling System [Online], [Accessed 22.02. 2014]. Available from World Wide Web: www. pdhonline. org/courses/m231/m231content. pdf. 2012.
[7] Mohammada A T, Mata S B, Sulaimana M Y, Sopiana K and Al-abidia A A 2013 Experimental Performance of a Direct Evaporative Cooler Operating in Kuala Lumpur *Int. J. Thermal & Env. Eng.* **6**(1) 15-20

[8] She X, Yin Y, Dong Y and Zhang X 2016 Investigation on air flow patterns of evaporative cooling and dehumidification process for a hybrid refrigeration system *App. Thermal Eng.***95** 79-94

[9] Koca R W, Hughes W C and Christianson L L 1991 Evaporative cooling pads: test procedure and evaluation *App.Eng. in Agriculture* **7**(4) 485-90

[10] Cruz V F, Perissinotto M, Lucas E M and De Moura D J 2006 Efficiency evaluation of pad cooling systems design with different pad materials. *In Proc. XVI. CIGR World Congress* 403-404

[11] Kocaturk U and Yildiz Y 2006 Some Performance Characteristics of Evaporative Cooling Pad At Three Air Velocities in Cukurova Region *J. Agric. Fac.* **21**(4) 101-8

[12] Rawangkul R, Khedari J, Hirunlabh J and Zeghmati B 2008 Performance analysis of a new sustainable evaporative cooling pad made from coconut coir *Int. J. Sust. Eng,* **1**(2) 117-31

[13] Watt J 2012 *Evaporative air conditioning handbook*. Springer Science & Business Media

[14] Saw I J and Fong O R 2019 Effects and Usefulness of Evaporative Cooling in Malaysia *Malaysia Green Building Council*

[15] Kulkarni R K and Rajput S P Comparative performance analysis of evaporative cooling pads of alternative configurations and materials 2013 *Int. J. Adv. Eng. & Tech.* **6**(4) 1524.

[16] Timmons M B, Baughman G R 1984 A plenum concept applied to evaporative pad cooling for broiler housing *Trans. of the ASAE* **27**(6) 1877-81

[17] Timmons M B, Baughman G R, Parkhurst C R 1981 Use of evaporative cooling to reduce poultry heat stress *Microfiche collection*

[18] Ganie A A, Kaur D, Nagra S S, Chopra S, Nayyar S 2018 Effectiveness of Various Cooling Systems during High Environmental Temperature on Production and Welfare Indices of Laying Pullets in Cage System of Rearing *J. Animal Research* **8**(5) 813-21

[19] Dağtekin M E, Karaca C, Yildiz Y I 2009 Long axis heat distribution in a tunnel-ventilated broiler house equipped with an evaporative pad cooling system *Animal Production Science* **49**(12) 1125-31

[20] Kulkarni R K, Rajput S P 2010 Theoretical performance analysis of jute fiber rope bank as media in evaporative coolers *Indian J. Sci. and Tech.* **3**(10) 1075-80